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TECHNICAL REPORT No. 103

Extraordinary Behavior of Atoms Near a Phase Conjugator

by

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Prepared for Publication

in

Coherence and Quantum Optics VI

Edited by L. Mandel and E. Wolf

Plenum Press, New York, 1989

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June 1989

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SECURITY CLASSIFICATION OF THIS PAGE

## REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) UBUFFALO/DC/TR-103			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Depts. Chemistry & Physics State University of New York		6b. OFFICE SYMBOL (if applicable)		7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code) Fronczak Hall, Amherst Campus Buffalo, New York 14260		7b. ADDRESS (City, State, and ZIP Code) Chemistry Program 800 N. Quincy Street Arlington, Virginia 22217			
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Office of Naval Research		8b. OFFICE SYMBOL (if applicable)		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract N00014-86-K-0043	
8c. ADDRESS (City, State, and ZIP Code) Chemistry Program 800 N. Quincy Street Arlington, Virginia 22217		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO.		PROJECT NO.	
		TASK NO.		WORK UNIT ACCESSION NO.	
11. TITLE (Include Security Classification) Extraordinary Behavior of Atoms Near a Phase Conjugator					
12. PERSONAL AUTHOR(S) Henk F. Arnoldus and Thomas F. George					
13a. TYPE OF REPORT		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) June 1989	
				15. PAGE COUNT 4	
16. SUPPLEMENTARY NOTATION Prepared for publication in <u>Coherence and Quantum Optics VI</u> , Edited by L. Mandel and E. Wolf, Plenum Press, New York, 1989					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	PHASE CONJUGATOR; ATOM LIFETIME		
			THEORETICAL STUDY TRANSITION DIPOLE GROUND-STATE FLUORESCENCE, (10)		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
<p>An atom near a phase conjugator (PC) is theoretically seen to behave quite differently than an atom in empty space or an atom near an ordinary (linear) surface. With two laser beams which pump the nonlinear crystal (PC), it is found that an atom in its ground state can fluoresce if it is sufficiently close to a PC. The possible mechanism involves the atomic transition dipole polarizing the PC, which then spontaneously emits a photon focused on the atom. With stimulated absorption and subsequent spontaneous emission, the net effect is that the atom remains in its ground state. <i>Keywords:</i></p>					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. David L. Nelson			22b. TELEPHONE (Include Area Code) (202) 696-4410		22c. OFFICE SYMBOL

# EXTRAORDINARY BEHAVIOR OF ATOMS NEAR A PHASE CONJUGATOR

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An atom near a phase conjugator (PC) behaves quite differently than an atom in empty space, or an atom in the vicinity of an ordinary (linear) surface. A spherical diverging wave, which is emitted by the atomic dipole  $\underline{\mu}$ , is reflected by the PC as a converging wave, and exactly focused on the emitting atom. This gives rise to a high probability for reabsorption of the photon that was just emitted. It can be anticipated that this mechanism leads to a strong enhancement of the effective lifetime of an excited state. We have calculated the spatial intensity distribution of the fluorescence, which is emitted in the half space to the 'left' of the PC (Fig. 1), and the total emitted power

$$P(t) = 2\epsilon_0 c r^2 \int d\Omega \langle \underline{E}^{(-)}(\underline{r}, t) \cdot \underline{E}^{(+)}(\underline{r}, t) \rangle \quad (1)$$

in the radiation zone. The angle brackets denote a quantum average, and  $\underline{E}^{(+)}(\underline{r}, t)$  is the positive-frequency part of the electric field operator in the Heisenberg picture. This  $\underline{E}^{(+)}$  is the solution of Maxwell's equations for this configuration, and it includes both the emitted field by the dipole and the field which is reflected by the PC. It is assumed that the PC is of the four-wave mixing type.

For a degenerate two-level atom we find the general expression

$$P(t) = \frac{\omega_0^4}{6\pi\epsilon_0 c^3} \text{Tr} \rho(t-r/c) \{ \underline{\mu}^{(-)} \cdot \underline{\mu}^{(+)} + c_{\parallel} \underline{\mu}_{\parallel}^{(+)} \cdot \underline{\mu}_{\parallel}^{(-)} + c_{\perp} \underline{\mu}_{\perp}^{(+)} \cdot \underline{\mu}_{\perp}^{(-)} \} \quad (2)$$

where (+) indicates the lowering part of the dipole operator (Schrödinger picture). Here,  $\rho(t)$  is the density operator of the atom only, and  $\omega_0$  is the atomic transition frequency. The two c-coefficients are found to be [1]

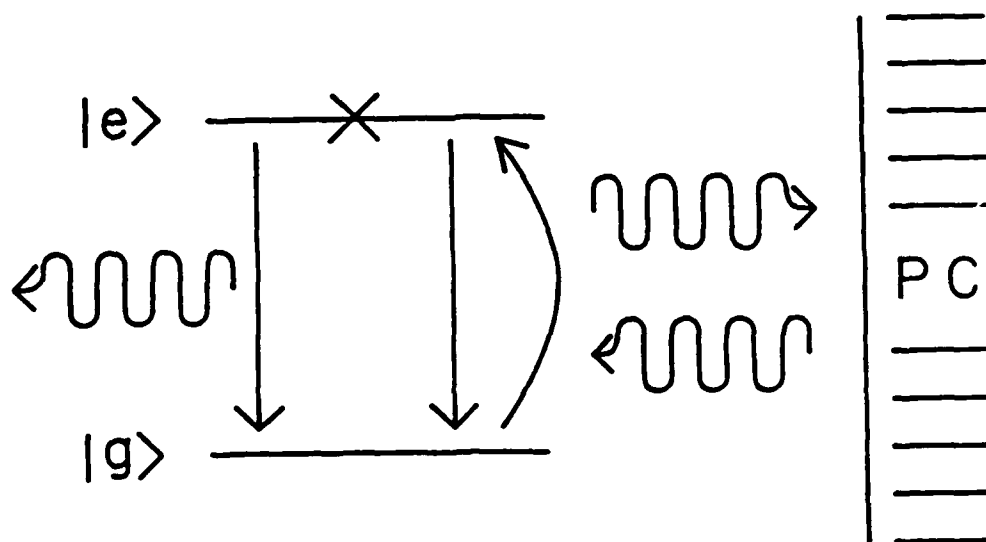


Fig. 1. Illustration of the possible mechanisms which give rise to the first term on the right-hand side of Eq. (4). A photon emitted to the left can be detected, but a photon that hits the PC never reaches the detector. This is either because this photon is absorbed by the medium, or it is absorbed by the atom after reflection. The figure depicts the second mechanism.

$$c_{\parallel} = \frac{3}{4} \int_0^1 du (1+u^2) |R(\omega_0, u)|^2, \quad c_{\perp} = \frac{3}{2} \int_0^1 du (1-u^2) |R(\omega_0, u)|^2, \quad (3)$$

where  $R$  is the Fresnel coefficient for reflection of a plane wave with the cosine of the angle of incidence on the surface of the PC equal to  $u$ . These coefficients also depend on the atomic level separation  $\omega_0$ , in general. In the case that the dependence of the Fresnel coefficients on the angle of incidence can be neglected, both  $c$ -coefficients reduce to  $|R|^2$ .

Expression (2) can be simplified considerably if we assume that the atom has only two states, and that  $R$  varies only slightly with the angle of incidence. Then Eq. (2) reduces to

$$P(t) = \frac{1}{2} A \omega_0 [n_e(t-r/c) + |R|^2 n_g(t-r/c)], \quad (4)$$

with  $A$  as the Einstein coefficient for spontaneous decay in empty space, and  $n_e$  and  $n_g$  as the populations of the excited and ground state, respectively. Nothing has been assumed about the time dependence of these populations, and so Eq. (4) holds also when the atom is not in its steady state.

Result (4) has two remarkable features. First, we notice that the first term, which is proportional to  $n_e$ , is just one half times the emission rate of an atom in empty space. This implies that the photons which are emitted towards the PC, and subsequently reflected (Fig. 1), are reabsorbed completely. No reflected photon passes the atom. We would like to emphasize, however, that this is only one of the tenable interpretations of the first term in Eq. (4). It is also possible that the PC absorbs the photon which is incident on its surface completely, and without reflection. This process would leave the atom in its ground state, rather than in its excited state, after occurrence of this process. Another possibility would be that both processes can happen.

Secondly, we see that  $P(t)$  has a term proportional to the population of the ground state. From this we conclude that an atom in its ground state can fluoresce, if it is sufficiently close to a PC. The possible mechanism is illustrated in Fig. 2. The presence of the atomic dipole moment polarizes the PC, which then spontaneously emits a photon, focused on the atom. Stimulated absorption and subsequent spontaneous emission gives rise to an observable photon at the left. The net effect is that the atom remains in its ground state. The required energy for this process is of course provided by the two laser beams which pump the nonlinear crystal.

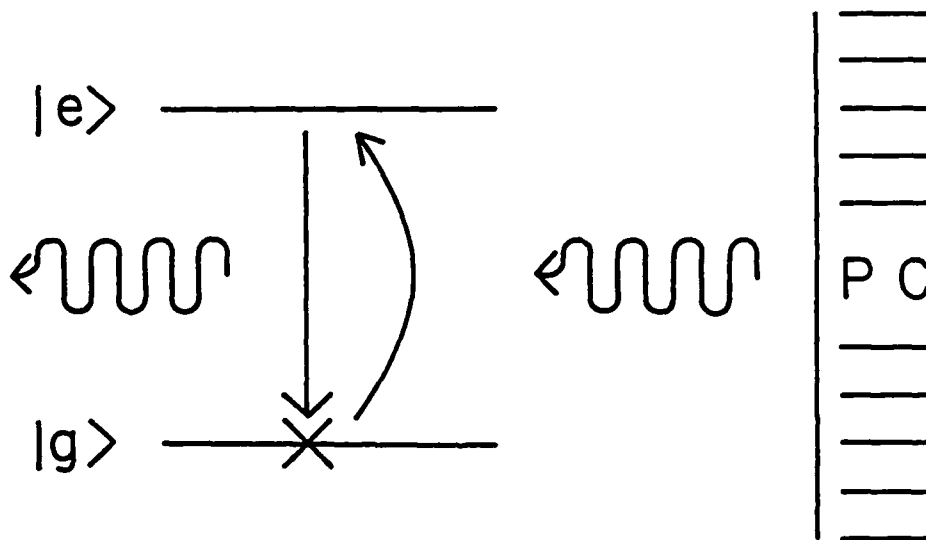


Fig. 2. As predicted by Eq. (4), an atom in its ground state can effectively emit a photon. Due to energy conservation this photon must first be extracted from the PC. The polarized PC spontaneously emits a focused photon, which is absorbed by the atom. Spontaneous excitation and subsequent decay produce a detectable photon at the left. After the process, the atom is again in its ground state.

This work was partially supported by ONR and AFOSR.

[1] H. F. Arnoldus and T. F. George, Opt. Lett. (1989), submitted.

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